FLIGHT SAFETY FOUNDATION

ALAR

APPROACH-AND-LANDING ACCIDENT REDUCTION

TOOL KIT

FSF ALAR BRIEFING NOTE 4.2

Energy Management

The flight crew's inability to assess or to manage the aircraft's energy condition during approach is cited often as a cause of unstabilized approaches.

Either a deficit of energy (low/slow) or an excess of energy (high/fast) may result in an approach-and-landing incident or accident involving:

- Loss of control;
- Landing before reaching the runway;
- Hard landing;
- Tail strike; or,
- Runway overrun.

Statistical Data

The Flight Safety Foundation Approach-and-landing Accident Reduction (ALAR) Task Force found that unstabilized approaches (i.e., approaches conducted either low/slow or high/fast) were a causal factor[1] in 66 percent of 76 approach-and-landing accidents and serious incidents worldwide in 1984 through 1997.[2]

These accidents involved incorrect management of aircraft energy condition, resulting in an excess or deficit of energy, as follows:

- Aircraft were low/slow on approach in 36 percent of the accidents/incidents; and,
- Aircraft were high/fast on approach in 30 percent of the accidents/incidents.

Aircraft Energy Condition

Aircraft energy condition is a function of the following primary flight parameters:

- Airspeed and airspeed trend;
- Altitude (or vertical speed or flight path angle);
- Drag (caused by speed brakes, slats/flaps and landing gear); and,
- Thrust.

One of the primary tasks of the flight crew is to control and to monitor aircraft energy condition (using all available references) to:

- Maintain the appropriate energy condition for the flight phase (i.e., configuration, flight path, airspeed and thrust); or,
- Recover the aircraft from a low-energy condition or a high-energy condition.

Controlling aircraft energy involves balancing airspeed, thrust (and drag) and flight path.

Autopilot modes, flight director modes, aircraft instruments, warnings and protections are designed to relieve or assist the flight crew in this task.

Going Down and Slowing Down

A study by the U.S. National Transportation Safety Board[3] said that maintaining a high airspeed to the outer marker (OM) may prevent capture of the glideslope by the autopilot and may prevent aircraft stabilization at the defined stabilization height.

The study concluded that no airspeed restriction should be imposed by air traffic control (ATC) when within three nautical miles (nm) to four nm of the OM, especially in instrument meteorological conditions (IMC).

ATC instructions to maintain a high airspeed to the OM (160 knots to 200 knots, typically) are common at high-density airports, to increase the landing rate.

Minimum Stabilization Height

"Recommended Elements of a Stabilized Approach" shows that the minimum stabilization height is:

Recommended Elements of a Stabilized Approach

All flights must be stabilized by 1,000 ft above airport elevation in instrument meteorological conditions (IMC) and by 500 ft above airport elevation in visual meteorological conditions (VMC). An approach is stabilized when all of the following criteria are met:

1. The aircraft is on the correct flight path;
2. Only small changes in heading/pitch are required to maintain the correct flight path;
3. The aircraft speed is not more than V_{REF} + 20 kt indicated airspeed and not less than V_{REF};
4. The aircraft is in the correct landing configuration;
5. Sink rate is no greater than 1,000 fpm; if an approach requires a sink rate greater than 1,000 fpm, a special briefing should be conducted;
6. Power setting is appropriate for the aircraft configuration and is not below the minimum power for approach as defined by the aircraft operating manual;
7. All briefings and checklists have been conducted;
8. Specific types of approaches are stabilized if they also fulfill the following: instrument landing system (ILS) approaches must be flown within one dot of the glideslope and localizer; a Category II or Category III ILS approach must be flown within the expanded localizer band; during a circling approach, wings should be level on final when the aircraft reaches 300 ft above airport elevation; and,
9. Unique approach procedures or abnormal conditions requiring a deviation from the above elements of a stabilized approach require a special briefing.

An approach that becomes unstabilized below 1,000 ft above airport elevation in IMC or below 500 ft above airport elevation in VMC requires an immediate go-around.

Source: FSF ALAR Task Force

- 1,000 feet above airport elevation in IMC; or,
- 500 feet above airport elevation in visual meteorological conditions (VMC).

Typical company policy is to cross the OM (usually between 1,500 feet and 2,000 feet above airport elevation) with the aircraft in the landing configuration to allow time for stabilizing the final approach speed and completing the landing checklist before reaching the minimum stabilization height.

Aircraft Deceleration Characteristics

Although deceleration characteristics vary among aircraft types and their gross weights, the following typical values can be used:

- Deceleration in level flight:
  - With approach flaps extended: 10 knots to 15 knots per nm; or,
  - During extension of the landing gear and landing flaps: 20 knots to 30 knots per nm; and,
- Deceleration on a three-degree glide path (for a typical 140-knot final approach groundspeed, a rule of thumb is to maintain a descent gradient of 300 feet per nm/700 feet per minute [fpm]):
  - With approach flaps and landing gear down, during extension of landing flaps: 10 knots to 20 knots per nm;
  - Decelerating on a three-degree glide path in a clean configuration is not possible usually; and,
  - When capturing the glideslope with slats extended and no flaps, typically a 1,000-foot descent and three nm are flown while establishing the landing configuration and stabilizing the final approach speed.

Speed brakes may be used to achieve a faster deceleration of some aircraft (usually, the use of speed brakes is not recommended or not permitted below 1,000 feet above airport elevation or with landing flaps extended).

Typically, slats should be extended not later than three nm from the final approach fix (FAF).

Figure 1 shows aircraft deceleration capability and the maximum airspeed at the OM based on a *conservative deceleration rate of 10 knots per nm on a three-degree glide path.*

For example, in IMC (minimum stabilization height, 1,000 feet above airport elevation) and with a typical 130-knot final approach speed,[4] the maximum deceleration achievable between the OM (six nm) and the stabilization point (1,000 feet above airport elevation and three nm) is:

10 knots per nm x (6 nm – 3 nm) = 30 knots.

To be stabilized at 130 knots at 1,000 feet above airport elevation, the maximum airspeed that can be accepted and can be maintained down to the OM is, therefore:

130 knots + 30 knots = 160 knots.

Whenever a flight crew is requested to maintain a high airspeed down to the OM, a quick computation such as the one shown above can help assess the ATC request.

Back Side of the Power Curve

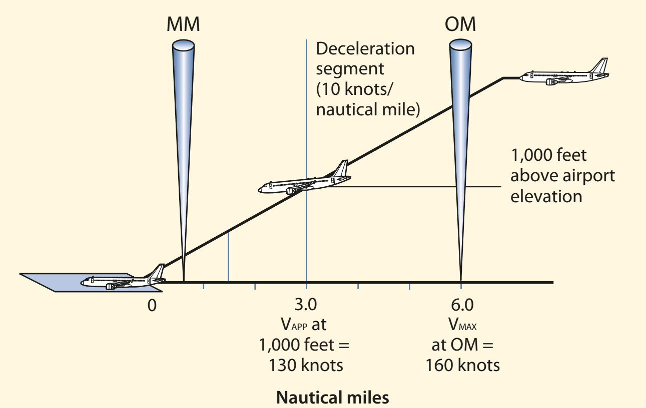
During an unstabilized approach, airspeed or the thrust setting often deviates from recommended criteria as follows:

- Airspeed decreases below V_{REF}; and/or,
- Thrust is reduced to idle and is maintained at idle.

Thrust Required to Fly Curve

Figure 2 shows the *thrust required to fly curve* (also called the *power curve*).

Typical Schedule for Deceleration on Three-Degree Glide Path From Outer Marker to Stabilization Height (1,000 Feet)



MM = middle marker; OM = outer marker; V_{APP} = final approach speed; V_{MAX} = maximum airspeed

Source: FSF ALAR Task Force

Figure 1

The power curve comprises the following elements:

- A point of minimum thrust required to fly;
- A segment of the curve located right of this point; and,
- A segment of the curve located left of this point, called the *back side of the power curve* (i.e., where induced drag requires more power to fly at a slower steady-state airspeed than the power required to maintain a faster airspeed on the front side of the power curve).

The difference between the available thrust and the thrust required to fly represents the climb or acceleration capability.

The right segment of the power curve is the normal zone of operation; the thrust balance (i.e., the balance between thrust required to fly and available thrust) is stable.

Thus, at a given thrust level, any tendency to accelerate increases the thrust required to fly and, hence, returns the aircraft to the initial airspeed.

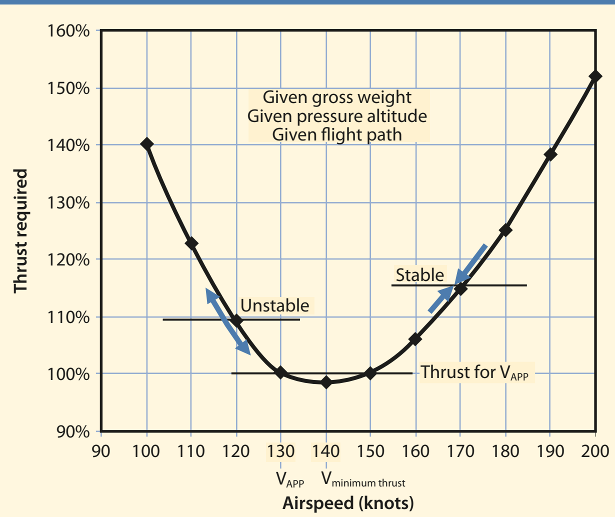
Conversely, the back side of the power curve is unstable: At a given thrust level, any tendency to decelerate increases the thrust required to fly and, hence, increases the tendency to decelerate.

The final approach speed usually is slightly on the back side of the power curve, while the minimum thrust speed is 1.35 times V_{SO} (stall speed in landing configuration) to 1.4 times V_{SO}.

If airspeed is allowed to decrease below the final approach speed, more thrust is required to maintain the desired flight path and/or to regain the final approach speed.

If thrust is set to idle and maintained at idle, no energy is available immediately to recover from a low-speed condition or to initiate a go-around, as shown in Figure 3, Figure 4 and Figure 5.

Thrust Required to Fly a Three-Degree Glide Path in Landing Configuration



V_{APP} = final approach speed

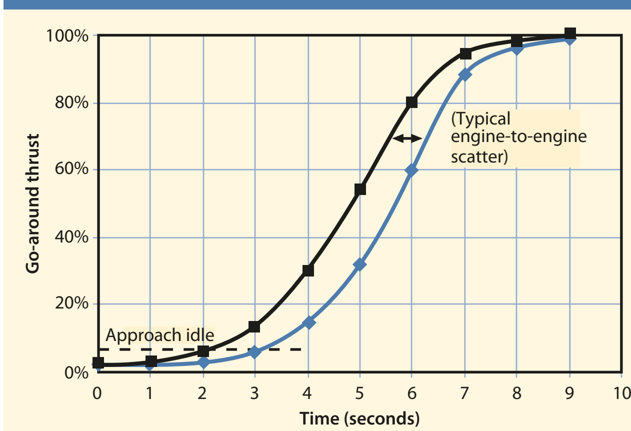
Source: FSF ALAR Task Force

Figure 2

Engine Acceleration

When flying the final approach with the thrust set and maintained at idle (approach idle), the pilot should be aware of the acceleration characteristics of jet engines (Figure 3).

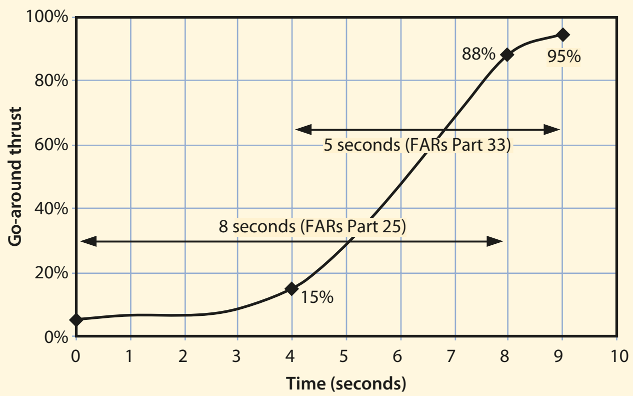
Typical Engine Response From Approach-Idle Thrust to Go-Around Thrust



Source: FSF ALAR Task Force

Figure 3

U.S. Federal Aviation Regulations (FARs) Requirements for Engine Response — Flight-Idle Thrust to Go-Around Thrust

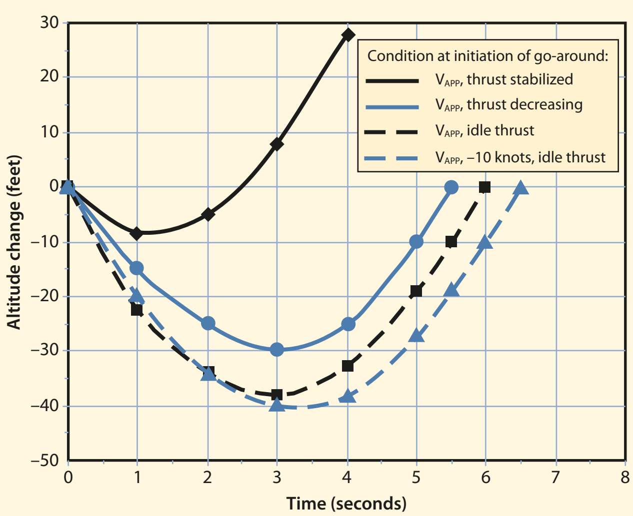


FARs Part 25 = Airworthiness Standards: Transport Category Airplanes
FARs Part 33 = Airworthiness Standards: Aircraft Engines

Source: FSF ALAR Task Force

Figure 4

Typical Altitude Loss After Initiation of a Go-Around (Aircraft in Landing Configuration)



VAPP = final approach speed

Source: FSF ALAR Task Force

Figure 5

By design, the acceleration capability of a jet engine is controlled to protect the engine against a compressor stall or flameout and to comply with engine and aircraft certification requirements.

For example, Figure 4 shows that U.S. Federal Aviation Regulations (FARs) Part 33 requires a time of five seconds or less to accelerate from 15 percent to 95 percent of the go-around thrust (15 percent of go-around thrust corresponds typically to the thrust level required to maintain the final approach speed on a stable three-degree approach path).

FARs Part 25 requires that a transport airplane achieve a minimum climb gradient of 3.2 percent with engine thrust available eight seconds after the pilot begins moving the throttle levers from the minimum flight-idle thrust setting to the go-around thrust setting.

Go-Around From Low Airspeed/Low Thrust

Figure 5 shows the hazards of flying at an airspeed below the final approach speed.

The hazards are increased if thrust is set and maintained at idle.

If a go-around is required, the initial altitude loss and the time for recovering the lost altitude are increased if the airspeed is lower than the final approach speed and/or if the thrust is set at idle.

Summary

Deceleration below the final approach speed should be allowed only during the following maneuvers:

- Terrain-avoidance maneuver;
- Collision-avoidance maneuver; or,
- Wind shear recovery maneuver.

Nevertheless, during all three maneuvers, the throttle levers must be advanced to maximum thrust (i.e., go-around thrust) while initiating the maneuver.

The following FSF ALAR Briefing Notes provide information to supplement this discussion:

- 6.1 — Being Prepared to Go Around;
- 7.1 — Stabilized Approach; and,
- 7.2 — Constant-Angle Nonprecision Approach.

Notes

1. The Flight Safety Foundation Approach-and-landing Accident Reduction Task Force defined *causal factor* as "an event or item judged to be directly instrumental in the causal chain of events leading to the accident [or incident]." Each accident and incident in the study sample involved several causal factors.

2. Flight Safety Foundation. "Killers in Aviation: FSF Task Force Presents Facts About Approach-and-landing and Controlled-flight-into-terrain Accidents." *Flight Safety Digest* Volume 17 (November–December 1998) and Volume 18 (January–February 1999): 1–121. The facts presented by the FSF ALAR Task Force were based on analyses of 287 fatal approach-and-landing accidents (ALAs) that occurred in 1980 through 1996 involving turbine aircraft weighing more than 12,500 pounds/5,700 kilograms, detailed studies of 76 ALAs and serious incidents in 1984 through 1997 and audits of about 3,300 flights.

3. U.S. National Transportation Safety Board. *Special Study: Flightcrew Coordination Procedures in Air Carrier Instrument Landing System Approach Accidents*. Report No. NTSB-AAS-76-5. August 18, 1976.

4. Final approach speed is V_{REF} (reference landing speed [typically 1.3 times stall speed in landing configuration]) plus a correction factor for wind conditions, aircraft configuration or other conditions.

Related Reading From FSF Publications

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Notice

The Flight Safety Foundation (FSF) Approach-and-Landing Accident Reduction (ALAR) Task Force produced this briefing note to help prevent approach-and-landing accidents, including those involving controlled flight into terrain. The briefing note is based on the task force's data-driven conclusions and recommendations, as well as data from the U.S. Commercial Aviation Safety Team's Joint Safety Analysis Team and the European Joint Aviation Authorities Safety Strategy Initiative.

This briefing note is one of 33 briefing notes that comprise a fundamental part of the FSF *ALAR Tool Kit,* which includes a variety of other safety products that also have been developed to help prevent approach-and-landing accidents.

The briefing notes have been prepared primarily for operators and pilots of turbine-powered airplanes with underwing-mounted engines, but they can be adapted for those who operate airplanes with fuselage-mounted turbine engines, turboprop power plants or piston engines. The briefing notes also address operations with the following: electronic flight instrument systems; integrated autopilots, flight directors and autothrottle systems; flight management systems; automatic ground spoilers; autobrakes; thrust reversers; manufacturers'/operators' standard operating procedures; and, two-person flight crews.

This information is not intended to supersede operators' or manufacturers' policies, practices or requirements, and is not intended to supersede government regulations.

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